

Fiber Lasers Get a Power Boost

FIBER lasers are powerhouses in the laser field and used for many applications such as industrial machining. Although a fiber laser is capable of producing kilowatts of power, it is ultimately limited by the intense laser light damaging the fiber. Six Laboratory physicists—Arun Sridharan, John Heebner, Paul Pax, Derrek Reggie Drachenberg, James Armstrong, and Jay Dawson—came up with an R&D 100 Award-winning solution to this problem: efficient mode converters for high-power fiber amplifiers.

In the team's system, one mode converter takes light from a traditional circular-core fiber and reformats it geometrically for injection into a Livermore-designed ribbon-fiber amplifier with a wide, rectangular core. (See *S&TR*, June 2011, pp. 16–18; April/May 2013, pp. 12–15.) A second converter located beyond the ribbon-fiber amplifier reformats the high-power output into a beam that is optimized for delivery to the target. This technology can potentially scale the power of fiber lasers

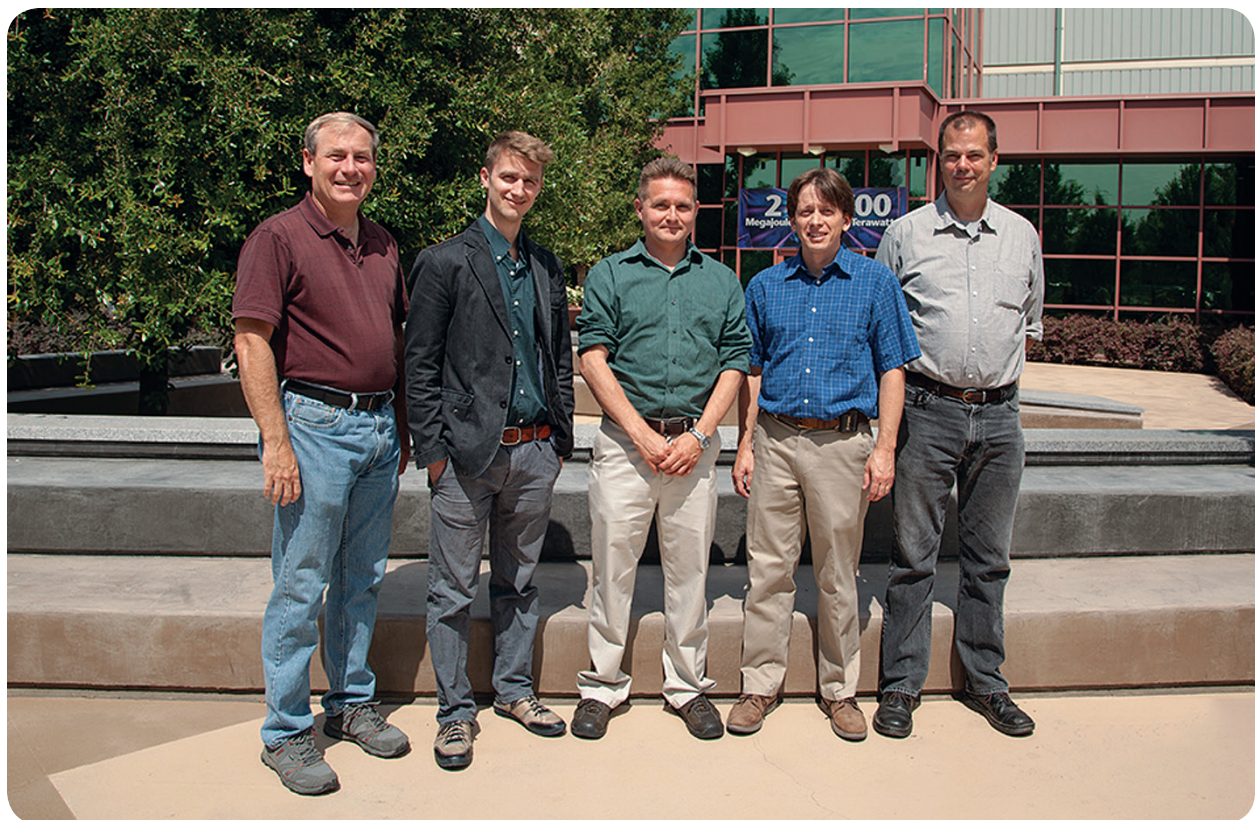
from a few kilowatts to 100 kilowatts, while maintaining high beam quality.

A Shape-Shifting Solution

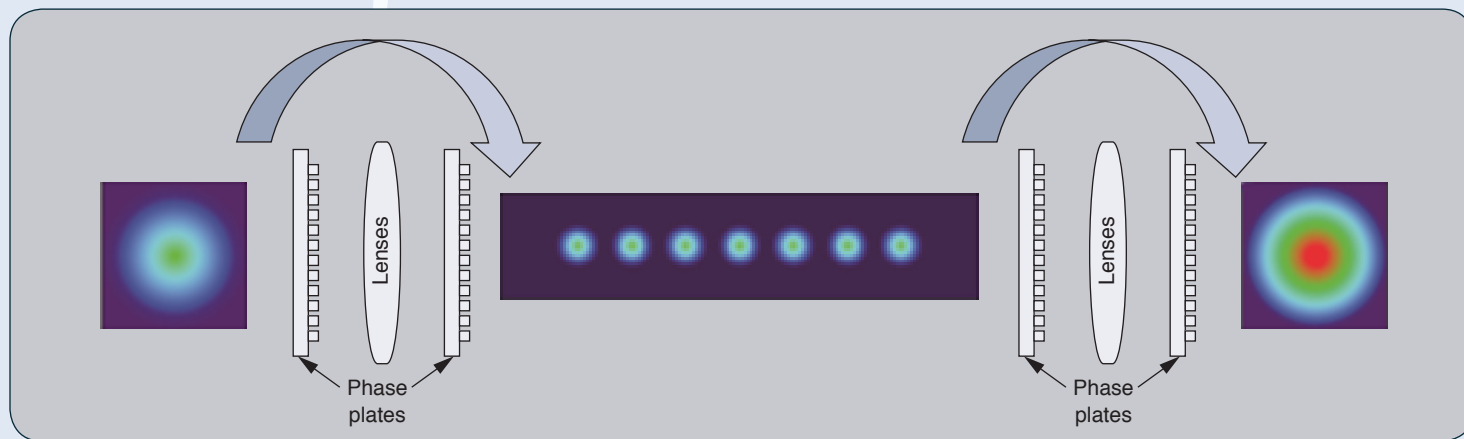
A fiber laser is typically constructed of an optical fiber doped with rare-earth elements such as erbium, ytterbium, and neodymium. Traditional fiber lasers and amplifiers are robust, compact, efficient, and reliable. Because of their inherent flexibility, they can readily deliver output to a movable focusing element—an important requirement for high-precision laser cutting and other applications. They can also be amplified to kilowatt levels of continuous output power, because the fiber has a high surface area to volume ratio. Commercial single-mode lasers are capable of reaching 10 kilowatts.

However, power amplification in these lasers is limited. Heebner explains, “We could increase the average power by combining multiple lasers. But, to maintain the tight focus at a distance, we

Development team for the mode converter system: (from left) Jay Dawson, Derrek Reggie Drachenberg, John Heebner, James Paul Armstrong, and Paul Pax. (Not shown: Arun Sridharan.)



and Winner



Key to the Livermore-developed mode converter system are the diffractive optical elements or “phase plates.” Each glass phase plate has an active area of approximately 1 square centimeter. The two phase plates at left, in combination with multiple lenses, convert low-power laser light (about 10 micrometers in diameter, shown here head-on) from a circular-core fiber to a form that is easily coupled into and amplified by a rectangular “ribbon” fiber (about 10 by 100 micrometers, also shown head-on). A second set of phase plates located beyond the ribbon-fiber amplifier reformats the high-power output into a beam that is optimized for target delivery. The mode converter system fits easily on a tabletop.

need the laser to operate in a single-mode, diffraction-limited configuration. In this configuration, the laser light can be amplified only so much before it damages the fiber. Our approach to increasing the energy output past this damage threshold is to spread the laser power over a larger area in the fiber.”

To obtain the larger area, the team moved from the traditional circular-core fiber amplifier to one with a rectangular core. The rectangular-core fiber allows the energy to spread over several peaks instead of being concentrated into the single peak of a circular-core, single-mode fiber.

“With the power distributed over many peaks or ‘lobes,’ we can amplify the laser light to a higher overall power without damaging the fiber,” says Heebner. The technology behind this operation is a mode converter. The converter modifies the single-mode laser light, while maintaining its beam quality, to a high-order mode that can be amplified to much higher power levels. The device makes this conversion with the help of two diffractive optical elements known as phase plates. (See the figure above.) The first plate takes the incoming light’s power distribution—often shaped with a Gaussian profile—and redistributes the power into multiple lobes that are appropriately matched to excite one of the ribbon-fiber modes. The second phase plate impresses the required phase to correct the wavefront of the distribution, yielding the alternating sign of the multiple lobes. Once the light is in the multiple-lobe configuration in the ribbon fiber, it can be safely amplified without destroying the fiber.

Finally, the now-amplified light passes through another pair of phase plates, similar to the first pair. These phase plates convert

the multiple-lobe, high-order mode light back into a single-lobe, low-order mode that is better suited for projecting and focusing on a target. The mode converter system accomplishes these tasks with more than 80 percent efficiency, far higher than any other approach. “In addition to being very efficient,” says Heebner, “our mode converter is simple, compact, and low cost.”

Increased Power Benefits Defense and Manufacturing

Fiber-laser applications typically require a lot of power—tens of kilowatts—all focused on a target that is a considerable distance from the source. With the Livermore-developed mode converter system, fiber lasers for national defense and industrial-machining applications could generate 7 to 10 times the average power of traditional fiber lasers over longer distances.

In addition, the mode converters could be incorporated with slab, rod, and gas lasers, which are typically used in industrial machining. “We foresee an even wider base of applications beyond our initial focus,” says Heebner. “We expect our mode converters to be of interest throughout industry and the departments of Energy and Defense.”

—Ann Parker

Key Words: circular-core fiber, fiber laser, industrial laser, mode converter, R&D 100 Award, ribbon fiber.

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